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THE CRITICAL ROLE OF INTELLIGENT SOFTWARE AGENTS IN ENABLING NET-CENTRIC COMMAND AND CONTROL

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The Vital Role of Intelligent Software Agents in Enabling Net-Centric Command and Control

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Abstract

The Net-Centric Operations and Warfare Reference Model (NCOW RM), Version 1.0, currently under development by the Office of the Assistant Secretary of Defense for Networks and Information Integration (OASD/NII), is the architectural touchstone for all Department of Defense information systems of the near- and long-term future. The reference model prescribes four sets of fundamental functionality: user/entity interaction services; intelligent assistance capabilities; net-centric services (encompassing communities of interest (COI) services, core enterprise services (discovery, mediation, collaboration, etc.), and environment control services); and resource provisioning services. The role and critical importance of the set of services that are to provide *intelligent assistance* to users of the Global Information Grid (GIG), and to its envisaged Net-centric Information Environment (NCIE), has yet to be fully delineated. We argue that the envisaged net-centricity in future warfare (command and control), business operations, and enterprise management is dependent upon a robust intelligent assistance capability based on the profuse use of intelligent agents throughout the GIG's NCIE.

1. Introduction

The Net-Centric Operations and Warfare Reference Model (NCOW RM)[1], under development by the Office of the Assistant Secretary of Defense for Networks and Information Integration (OASD/NII), is the architectural touchstone for all Department of Defense (DoD) information systems of the near- and long-term future. The reference model presents an architectural template for the Global Information Grid's Net-centric Information Environment (GIG/NCIE, hereafter referred to simply as the NCIE). Depicted in

[1] The "Net-Centric Operations and Warfare Reference Model, Version 1.0" [1] is documented in terms of the "Department of Defense Architectural Framework" (DODAF) [2] and currently consists of an AV-1 (Overview and Summary Information), an AV-2 (Integrated Dictionary), an OV-1 (High-level Operational Concept Description), an OV-5 (Activity Decomposition and Activity Model), an SV-1 (Systems Interface Description), an SV-2 (Systems Communications Descriptions), and a TTV (Target Technical View).

Figure 1, the NCOW RM prescribes four sets of fundamental functionality: (1) user/entity interaction services; (2) user/entity assistance services; (3) net-centric services; and (4) resource provisioning services.[2]

The substance of the NCOW RM resides largely in the activity labeled "A3 – Provide Net-Centric Services," for it includes three major sub-activities: A31 – Provide Core Services, A32 – Provide COI (Community of Interest) Services, and A33 – Perform Environment Control Services. This latter set of services or capabilities is critically important in assuring the security, efficiency, and overall effectiveness of the NCIE. It can be considered the "back-plane" upon which the user/entity, core, and COI services are instantiated and controlled. As such, it surrounds and permeates all other NCIE services and capabilities.

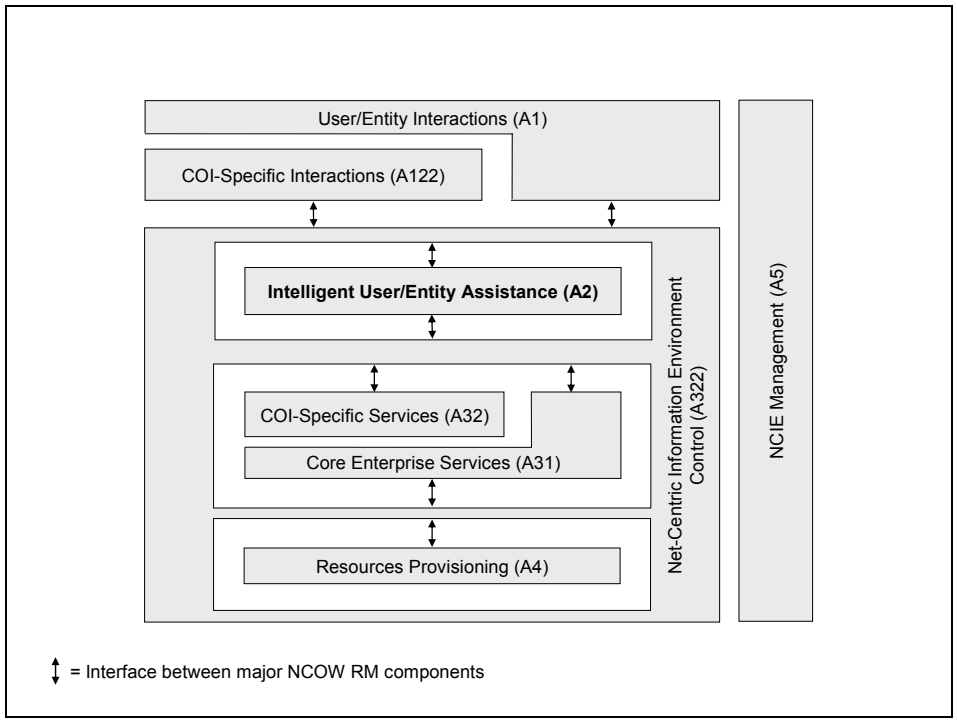

Figure 1. Net-Centric Operations and Warfare Reference Model

[2] The role of a fifth major branch that appears on the NCOW RM Activity Decomposition "node tree," the one labeled "A5 – Manage Net-Centric Information Environment," is explained below.

While environment control services provide the crucial security needs of the NCIE, the user/entity assistance services will provide a critically important *enabling* role. It is our contention that the goals of net-centricity may not be achieved if user/entity assistance services are not designed and deployed as a sophisticated set of intelligent agents that enable effective interactions between NCIE users and the services and capabilities the NCIE is being designed to provide. This paper presents the basis for this contention, describes the kinds of intelligent agents most likely to be needed, and highlights the challenges in design and development that lie ahead.

2. Why are Intelligent User Assistance and Software Agent Technology Necessary for Net-Centricity?

There are really two questions here: why is intelligent user assistance needed for net-centricity? And, why is agent technology necessary to implement intelligent user assistance? To answer either of these questions, we need a rough understanding of net-centricity. In the context in which we're interested (i.e., military business operations and warfare), net-centricity is

> an information superiority-enabled concept of operations that generates increased combat power by networking sensors, decision makers, and shooters to achieve shared awareness, increased speed of command, higher tempo of operations, greater lethality, increased survivability, and a degree of self-synchronization. In essence, [net-centricity] translates information superiority into combat power by effectively linking knowledgeable entities in the battlespace [3].

The basic architecture of the information systems needed to implement the net-centric vision comprises, in part, five core services: information discovery, storage, mediation, messaging, and collaboration. Storage and messaging are self-explanatory, although it should be borne in mind that "messaging" encompasses not only user-to-user messaging services like e-mail but just about any form of user-to-system entity communications.

Collaboration refers to the services that enable or otherwise promote the formation of teams of users to address a common problem or issue. These teams may be as simple as two people interacting with each other to coordinate a response to a security incident, or as elaborate as hundreds or even thousands of interacting and cooperating elements of a command and control system. As we will see, effective collaboration requires a means to establish a virtual, and generally non-persistent, "community of interest" of users (or entities) who may be unaware that other users share their immediate interests and could contribute to the solution of the immediate problem. It is our contention that *discovery* and *matchmaking* agents represent a technology especially suited to support (non-persistent) COI formation.

Mediation can refer to either (1) the brokering of services or interactions between users or (2) the mediation necessary to integrate multiple pieces of information from different sources. This second sense of "mediation" goes beyond resolving information expressed in different data processing formats. The interesting and important forms of information mediation address the issue of *semantic context resolution*: in the context of what functional or organizational *domain* is this information to be interpreted?

This basic architectural framework has been captured in the NCOW RM, v.1.0. This reference model provides an architectural template for achieving complete GIG *net-centricity* by 20xx (nominally 2020). As noted above, it delineates four major system services: user/entity-NCIE interactions; user/entity assistance services; core enterprise, COI, and environment control services; and resource provisioning services. A fifth element of the NCOW RM—NCIE Management[3]—is actually just a special instance of the first ele-

[3] Labeled "A5" in the NCOW RM v.1.0 OV-5.

ment: user/entity-NCIE interactions. It outlines the management activities necessary to assure the provisioning, operations, and security of the NCIE. In effect, the Net-centric Information Environment Management activities of the NCOW RM are orthogonal—like the more generic "user/entity-NCIE interactions" branch of the reference model—to the "core" services or capabilities of the model. It is important to realize that the user/entity-NCIE interactions and the NCIE management activities depicted in the NCOW RM are both user/entity *interactions* with the NCIE. They outline the kinds of things *users* do via the NCIE in order to perform their mission. It is also important to realize that these "users" include both human and system entities.

The NCIE is envisaged as a global net-centric system-of-systems that supports the warfighter, DoD business operations, and DoD enterprise management. It is neither possible nor advisable to distinguish between "users" of the NCIE and the NCIE itself. Many, if not most, *users* of the NCIE will be components of the NCIE. Indeed, it may be more useful to think of the envisaged NCIE as that "view" of the global information systems world that is DoD-focused. This includes not only all typical GIG users, that is, all DoD military and civilian personnel, but also all DoD suppliers, and its allies and coalition partners. Moreover, the class of GIG "users" includes DoD's information systems as information "producers" and information "consumers." The DoD GIG is inherently and inevitably recursive.

3. What Roles Must Intelligent User Assistants Play?

The importance of the role that user assistance services will play in the NCIE should not be underestimated. The set of user assistance services will be a vitally important interface between NCIE users (again, including NCIE components themselves) and the

NCIE proper. It makes the interface between users and NCIE services—that is, the integration function—explicit. User assistant services are both end-user and NCIE services "facing." Their role is both to assist users in availing themselves of NCIE capabilities and in enabling NCIE capabilities to identify and then provide services to those users for whom the services were deployed. The user assistant service of the NCIE is more than a "broker." It is conceived as a "match-maker." Its core function is to match user (again, not necessarily "end"-user) needs with NCIE services *and* to match NCIE services with those users who could benefit most from the service offering. The user assistant relieves the user of the problem (and computational burden) of determining where to go (of what service to avail itself) to accomplish user objectives. Likewise, the assistant unburdens the many services of the NCIE from having to determine what users need to be informed, alerted, or otherwise apprised of new information or capabilities. In a way, the user assistant will play a role not unlike that of the old time telephone switch-board operator, connecting telephone user to telephone user based on internal *knowledge* of the circuitry of the telephone system and its customers. The envisaged user assistant services of the NCIE will possess analogous knowledge, of both the users—their privileges and roles (and hence their information needs)—and the "services" that the NCIE can provide.

Is such a user assistant function really necessary? Theoretically it is not. There is no theoretical reason why the "service discovery" functionality cannot be built into its NCIE-interface repertoire. Similarly, there's no theoretical reason why NCIE services cannot "discover" in near-real time those "users" most likely to be interested in the information or capability available from the service. However, practically—from both a computational and conceptual point of view—it makes far more sense to relieve the enti-

ties involved in an exponentially-expanding set of pair wise-interconnections of the need to keep track of "what is of interest to whom." Rather to focus on the entity's immediate goal and function, and to give up the "matching" of the need to the provider (and vice versa) than having to worry about it oneself.

What general matchmaking roles or functions does a net-centric information environment require of intelligent user assistants? Put another way, what user/entity—net-centric services does the user assistance service need to mediate between or broker among? More specifically, what new requirements does net-centricity lay upon the NCIE user, and, conversely, what new requirements does net-centricity impose upon the NCIE itself? The predominant new onus layered upon the user in a net-centric world is to "post" (before processing)[4] to the environment any data that may be of value to other NCIE users. In effect, this means that users who gather or produce data must assume that their data is of value or relevant to other NCIE users and, therefore, to store that data in an accessible "public" or "controlled and shared" space. Moreover, these same users must describe the data (i.e., provide appropriate meta-data) that will enable the other NCIE users with a possible interest in the data to discover and, with appropriate authorizations, avail themselves of that information. As we will see below, this latter function imposes two additional requirements on the intelligent user assistants. They must help users find information that might be of interest or value. They must also help net-centric enterprise services themselves "find" the users who should be aware of the existence of the information. The street between users and the information they need and the information and the users that need it is most effective if it's two-way.

As an information provider-oriented user, then, there are two major requirements for which the user assistants may be crucially important: (1) deciding if and to what extent new data (either produced or collected) should be made more widely available, and (2) how best to characterize that information—what meta-data descriptors should be supplied—to foster easy discovery and subsequent use. While these two tasks are distinct, they are not unrelated. It's easy to imagine how the proper meta-data will be derived, in large part, from the considerations that have to go into deciding if the information ought to be shared among a larger NCIE user community. It's hard to imagine, for instance, how one could decide that data ought to be shared if one has no idea with whom it should be shared. But if one has some idea who might want to see or otherwise be aware of the existence of the information, then one already has a key piece of meta-data: "of possible interest to X" (where "X" denotes a class of users defined functionally, organizationally, or in some other appropriate way). Note that by "logically centralizing" in user assistant services the support for end users as they specify information meta-data, there is a far greater likelihood that all NCIE meta-data will be underpinned by a common, uniform, coherent, and otherwise fully "integrated" (meta-) data dictionary. The net-centric user assistant services is an ideal vehicle for ensuring that meta-data is prepared and used in a consistent fashion across the entire enterprise. Notice that the meta-data characterization process is also very likely to help determine to what extent the data should be shared (i.e., made "public" and "discoverable").

In addition to helping to decide the basic question, ought this information be shareable, the intelligent user assistants can advise on matters of security classification and

[4] This is the second "P" of the acronym, TPPU, or "Task, Post, Process, Use," that is

other security considerations. The user assistance services could even assume responsibility for the storage of the data in the appropriate repositories.

4. What Types of Intelligent Agents are Necessary to Provide these Roles?

Before trying to characterize the specific kinds of intelligent agents we foresee as necessary to enable an effective net-centric information environment, we should pause to explain what an intelligent agent is. We define the term "software agent" as that which denotes a software entity that is capable of independent (or autonomous) action within unpredictably changing (software) environments. Computer "viruses," for instance, are malevolent species of the genus "software agent." A more benign and useful kind of software agent are intelligent (software) agents, that is, those which, in addition to the autonomy characteristic of software agents, in general, exhibit behavior that mimics to some extent some of the human behavior to which we ascribe the adjective "intelligent." This behavior includes situation assessment, problem solving, inter-agent communication, and—most important—some degree of learning or adaptation. It's this latter behavior that is logically necessary for intelligent agents to operate autonomously for extended periods of time within unpredictably dynamic environments. It is also the characteristic that separates intelligent software agents from today's run-of-the-mill viruses that too often plague today's Internet; computer viruses have, as yet, (fortunately too) little adaptive capability. The adaptiveness distinction between computer viruses and intelligent agents is today simply in the level of sophistication of their programmers.

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supposed to supercede TPED, "Task, Process, Exploit, and Disseminate."

We envisage five basic sorts of user assistants (i.e., intelligent agents) playing a crucial role in the realization of the net-centric vision: information discovery, information dissemination, semantic mediation, matchmaker, and user interface.

• *Information discovery agents* assist in the discovery of information. Their function is to find, access, and retrieve information, on behalf of the user, from the profusion of information—in databases, websites, public news feeds, and shared data files—available both within the NCIE and on the public Internet as a whole.

• *Information dissemination agents* are intended to perform a more proactive function, that is, to maintain awareness, and either to alert users to the existence of potentially relevant or valuable information or to disseminate the information itself (the "smart push") to those users most likely to need the information. Information dissemination agents must both "understand" the information needs of its clients as well as constantly *monitor* for new and relevant information amidst the always changing information sources from which it feeds. This latter requirement imposes a significant performance mandate. The former requirement—"understanding" its client's information needs—imposes a substantial and genuinely "cognitive" task. The agent must not only "know," in some sense, what its client needs to know, but it must also be able to parse and "understand" the import or essence of the information that comes within its purview. This task is currently feasible, given a robust and widely accepted and used meta-data tagging regimen (based on XML, DAML, OWL, or similar meta-data frameworks[5]). It is not cur-

[5] XML (eXtensible Markup Language) is well known. "DAML" stands for "DARPA Agent Markup Language," an extension of XML and the Resource Description Framework (RDF). RDF is used to represent information and to enable the exchange of knowledge on the Web. OWL is a W3C (World Wide Web Consortium) recommendation for a

rently possible if the agent must parse and then semantically interpret free (or semantically untagged) text.[6] This latter fact underscores the importance of a DoD data strategy that is focused on data-tagging and registry within the GIG.[7]

- *Semantic mediation agents* are needed to translate domain (or Communities of Interest) "ontologies" among different domains. A (computational) ontology is just "the common backbone taxonomy of relevant entities of an application domain."[8] The problem—and one should not underestimate its difficulty—is to devise a dictionary that enables translation between pair-wise domains. A "full-up round," for example, is defined differently by the US Air Force, Navy, and Marines. The different definitions, fortunately, are reconcilable. With a sufficient broadening of the semantic envelope (in this case, with respect to time and subordinate tasks), the two terms can be defined with respect to a third term that subsumes (and can be used as the translation dictionary for) both.

- *Matchmaker agents* are "second-order" or "meta-agents" used to provide inter-agent negotiation in the attempt to facilitate the best user service by the system agents. A matchmaker agent, for instance, might be able to simultaneously "match" an information

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"Web ontology language" to be used to publish and share ontologies in support of advanced Web search, software agents, and knowledge management.

[6] Noteworthy progress is being made constantly, however. The gap between human beings who desire to communicate, both with other humans and machines, and the machines that are being built to understand and communicate with humans is narrowing, and will continue to do so.

[7] "DoD Net-Centric Data Strategy" [4].

[8] It's usual these days to distinguish "computational" from "philosophical" ontology. Barry Smith defines a computational ontology as the common backbone taxonomy of relevant entities of an application domain. Philosophical ontology, a branch of philosophy, "is the science [*sic*] of what is, of the kinds and structures of the objects, properties and relations in every area of reality" [5]. This distinction is one of scope rather than of kind.

discovery agent's task to a related item on a dissemination agent's task list and fortuitously "short-circuit" the agent community's workload. The importance of matchmaker agents in a maturing net-centric information environment might be likened to the importance of net-aware operating systems today.

- *User interface assistance agents* are the more mundane of the user assistants envisaged for the NCIE, although they will play an important role in terms of usability. There are two sorts: *basic interface agents* that accept and then display (possibly graphically or verbally) responses (output, results) from the NCIE; *personal assistant agents* that facilitate or otherwise maximize a user's interactions with the NCIE. The user interface assistance agents are more oriented to the user's personal idiosyncrasies than to the broader issues of global information discovery, mediation, and dissemination. The user interface assistance agent will impose a configuration burden upon the user inversely proportional to its ability to "learn" about the needs and preferences of its client. Interface agents could also be the essential means to standardize service invocations, that is, interpreting user "speak" into a more formal syntax and semantics for use in calls to NCIE services.

A mapping of these various kinds of agents to the intelligent user assistance functions they can most readily implement is summarized in Table 1.

5. What Challenges with Respect to Design and Development do the Use of Agent Technology Impose on GIG Architects and Developers?

User assistant agents (or services), in order to be genuinely effective and useful, will require an "ontology" that can encompass the DoD enterprise. There is only a remote chance that a DoD-wide common "ontology" (or data model) will emerge in time for a 20xx deployment of the NCIE. The best hope is for mutual commensurability—and

hence translatability—between the ontologies that inform the information systems of each DoD component. It's not necessary—nor even necessarily desirable—for the each

	Function Supported on Behalf of:	
Intelligent Agent Type	***User/Entity***	***NCIE Service***
Information Discovery	Find, access, retrieve information	
Information Dissemination		Discover and disseminate information
Semantic Mediation	Information translation and tagging	Information translation
User Interface:		
Basic User Interface	Tailor interface to user	
Personal Assistant	Enhance user interactions	
Matchmaker	Inter-agent negotiation	

Table 1. Agent-to-Support Function Mapping

DoD component to talk the same language. It is important, however, that there be an Army-Air Force dictionary that a capable *machine* interpreter can use to translate the language of one Service into that of the other. This is not especially difficult, albeit it may be tedious, for it not only requires agreement on the precise definitions of *all* important (not only *key*) terms, but the "retrofitting" of any newly required attributes to existing data sources (e.g., databases). If an Air Force "full-up round" means "complete on-hand aggregation of major components comprising a missile," then the object attribute "*time* to assemble, bench-check as serviceable, and make ready for immediate load-out" needs to be added to the underlying database.

Designers and developers will have to engineer the intelligent user assistants to a level of reliability and "trust" that will push the limits of current technology. Intelligent agents must negotiate between users and NCIE services, and among NCIE services (e.g., between discovery services and mediation services). These two classes of interaction

(user/entity-to-NCIE and NCIE-services-to-NCIE-services) adds a level of complexity that has yet to be fully thought through in terms of either interrelated functionality or security. We hope this paper begins to outline the complexities involved.

Autonomous agent technology is most effective if it can be deployed as mobile code, that is, as "software obtained from remote systems outside the enclave boundary, transferred across a network, and then…executed on a local system without explicit installation or execution by the recipient" [6]. The widespread use of mobile code technology—in particular, mobile agents—becomes inevitable when we need a "general framework in which distributed, information-oriented applications can be implemented efficiently and easily, with the programming burden spread evenly across information, middleware, and client providers" [7]. Unfortunately, mobile code "has the potential to severely degrade DoD operations if improperly used or [inadequately] controlled" [6]. As a consequence, DoD has issued guidance in the use of mobile code in DoD system networks that can communicate with other networks. Current policy is conveyed in [6] which groups mobile code technologies in three categories (severe, moderate, limited) according to the level of threat they pose to DoD information system operations. Category 1 mobile code (e.g., Unix shell and DOD batch scripts when used as mobile code) is allowable only when signed with a DoD-approved PKI (public key infrastructure) code signing certificate and the code is obtained from a trusted source. Category 2 mobile code (e.g., Java applets) may be used if the code is obtained from a trusted source (i.e., a "source adjudged to provide reliable software code or information and whose identity can be verified by authentication") over an assured channel (i.e., "a network communication link that is protected by a security protocol providing authentication and data integrity, and

employs US Government approved cryptographic technologies whenever cryptographic means are used") [6]. While the use of Category 3 code (e.g., Javascript) is basically unrestricted, the technology offers limited functionality, "with no capability for unmediated access to workstation, host, and remote system services and resources" [6].

The prospects for widespread use of intelligent user assistance agents—to the extent they will need to function as mobile code—will remain limited by the lack of an effective and widely employed identity and authentication (I&A) system within DoD. But progress in the deployment of an effective DoD I&A is inevitable as the importance of the more general environment controls needs (the A322 component in Figure 1) is more broadly appreciated and then realized. Net-centricity in its fullest sense cannot be achieved until the vital role that intelligent software agents will need to play in enabling net-centric operations and warfare is more widely recognized.

6. Summary

The NCOW RM, Version 1.0, is the evolving architectural framework for all DoD information systems of the immediate and long-term. The role and importance of the set of services that are to provide *intelligent assistance* to users of the NCIE has yet to be fully delineated. We argued that the envisaged net-centricity in future warfare (command and control), business operations, and enterprise management is dependent upon a robust intelligent assistance capability based on the profuse use of intelligent software agents throughout the GIG and the NCIE. Intelligent assistance, in general, and intelligent software agent technology, in particular, is important for the success of the emerging net-centric paradigm in Department of Defense command and control (C2) and business operations information systems architectures. We outlined the role that intelligent assistance

capabilities need to play in the overall integration of the separate sets of functional capabilities as set forth in the NCOW RM in order to achieve the net-centric objectives. We described the types of specific intelligent assistance services that will be required to enable net-centric C2 and outlined the challenges the design and development of these capabilities will present. We contended that the NCIE can only achieve its full potential if a robust set of intelligent agents, many deployed as mobile code, becomes an integral part of the GIG/NCIE. Deployment of mobile code within DoD, however, remains contingent on the deployment of an effective identity management system.

Acknowledgments

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Vital Role of Intelligent Software Agents in Enabling Net-Centric Command and Control

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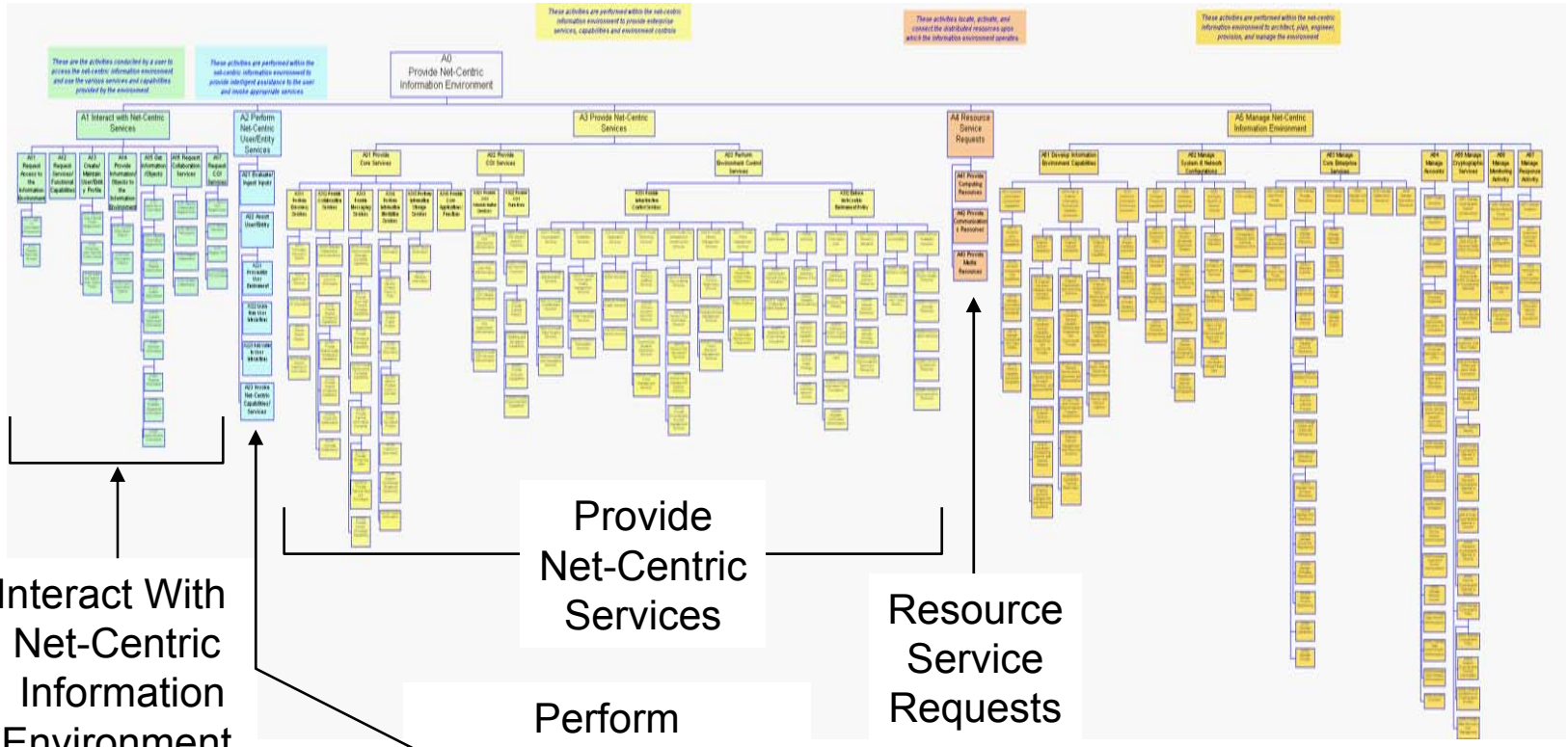
Contention

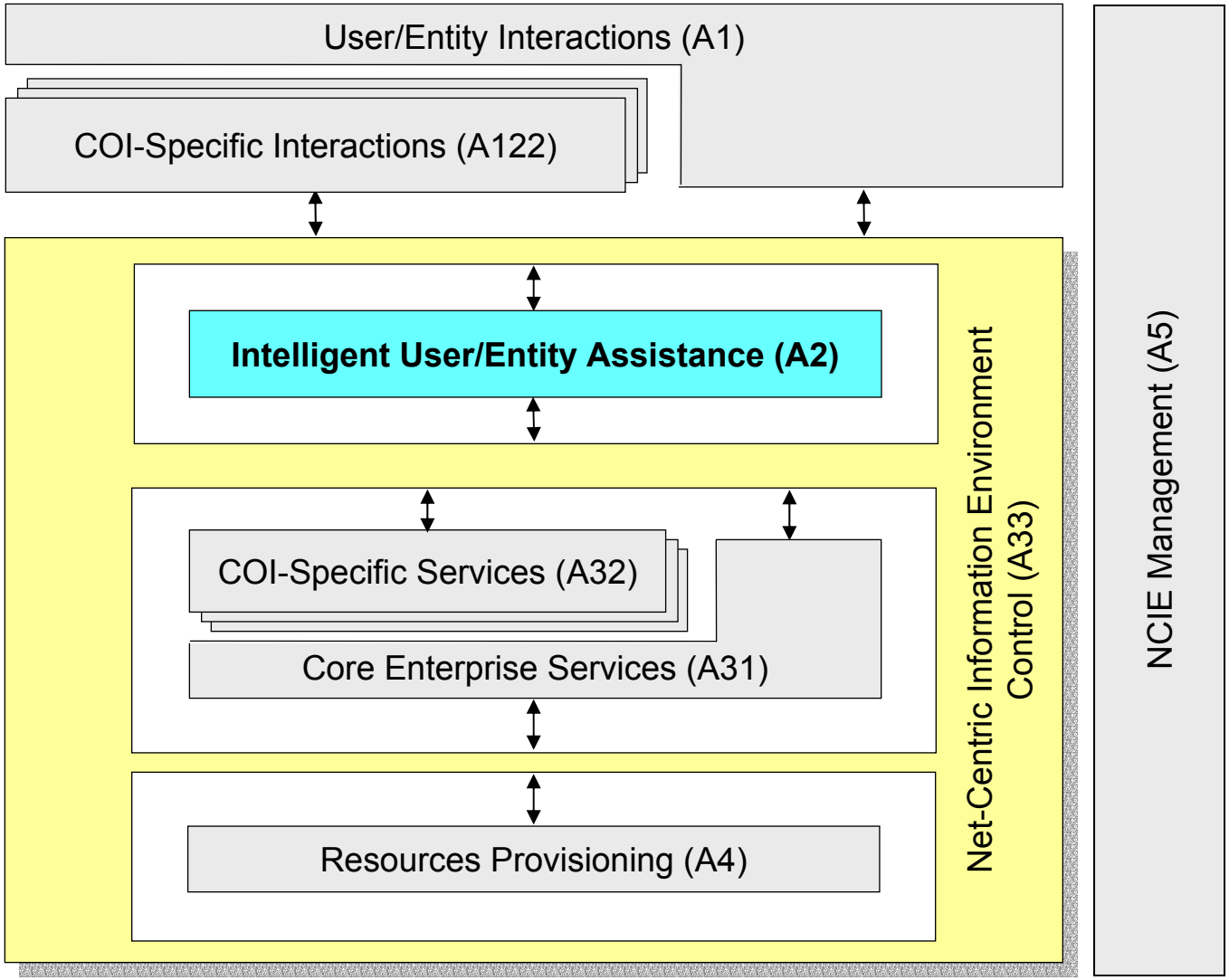
- The net-centric GIG will require *intelligent* user assistant services—to an extent or degree not fully appreciated today
- Therefore, intelligent software agents must have a paramount role in the GIG in order to achieve a transformation to net-centric operations and warfare

Reference Model Activity Decomposition

"Provide Net-Centric Info Environment"



NCOW Reference Model as "Stack"



↕ = Interface between major NCOW RM components

Net-Centric
Core Enterprise Services

- Information discovery
- Storage
- Mediation
- Messaging
- Collaboration
- **User Assistance**
- IA/Security
- ESM
- Applications

User Assistant Services (from DISA Workshop)

- Definition: Automated or manual capabilities that learn and apply user preferences and patterns to assist users to efficiently and effectively utilize GIG resources in the performance of tasks
- On-line help
- Language translation service
- User profile service
- Human-Machine interface
- User training
- User surrogate

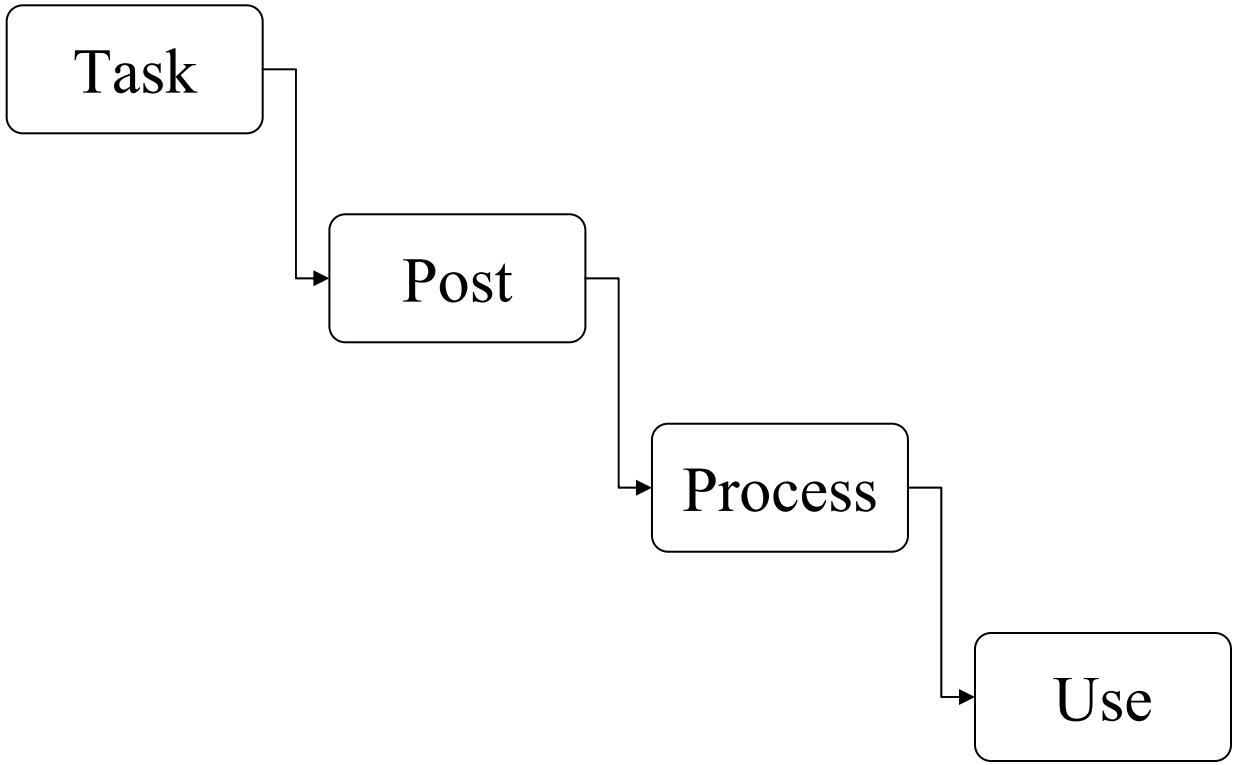
Intelligent User Assistant Roles

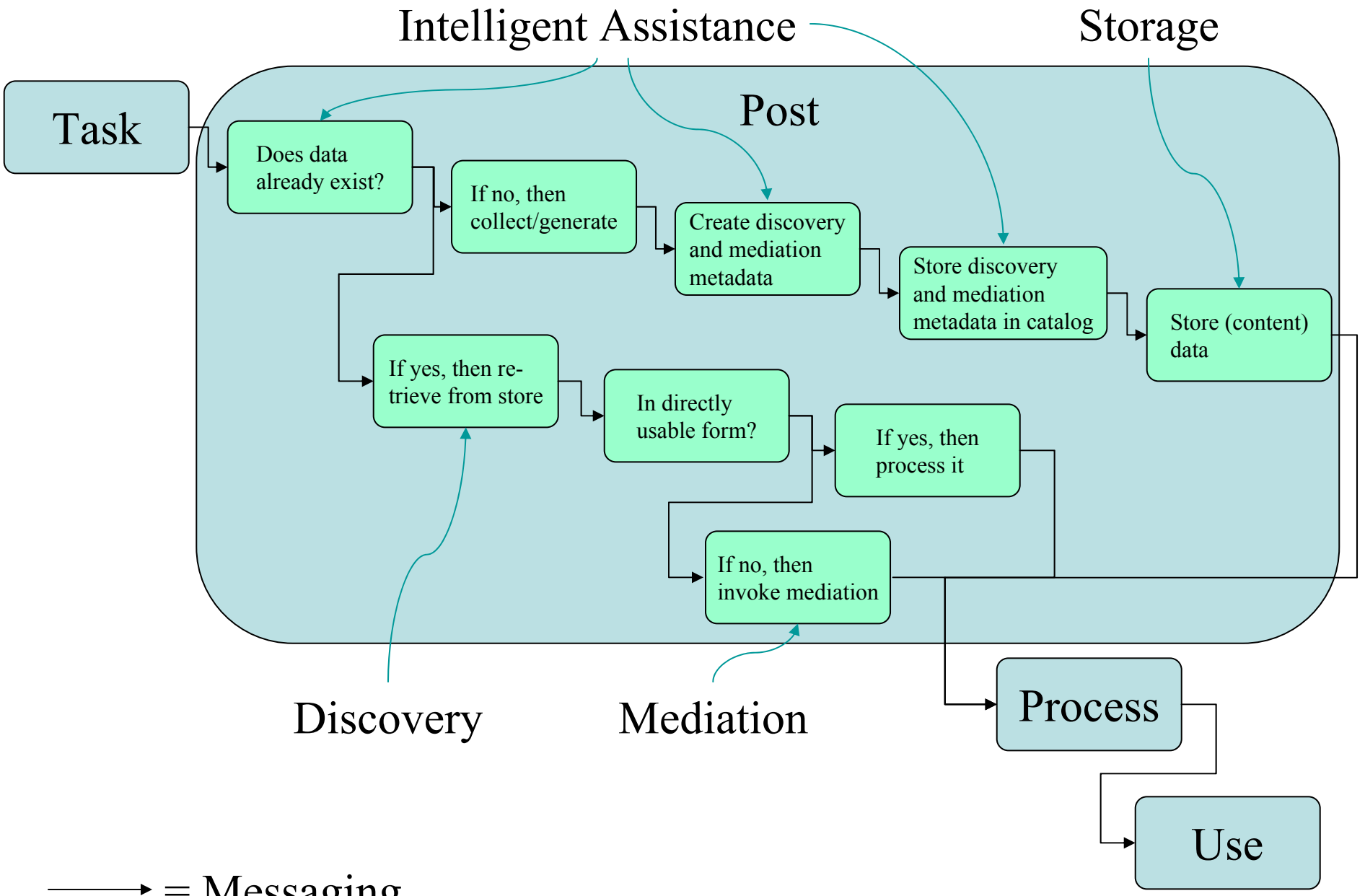
- Key interface between users (interacting with the NCIE (A1)) and the core of the NCIE (A3 and A4)
  - Broker or matchmaker
  - Shifts “what is of interest to whom” burden from other core services to the user assistant
  - “Centralizes” GIG intelligence

Requirements Imposed by Net-Centricity

- Users must “post” (before processing)
  - Store data in accessible space
  - Describe (meta-data)
- Users will need help in deciding if new data (produced or collected) should be posted
- Users will need help in describing that data if it is to be shared
- Net-centric user assistant is ideal vehicle for ensuring that meta-data is underpinned by a common, uniform, coherent, “integrated” data dictionary

“TPPU”




Intelligent Assistance
Storage
Task
Post
Does data already exist?
If no, then collect/generate
Create discovery and mediation metadata
Store discovery and mediation metadata in catalog
Store (content) data
If yes, then re-trieve from store
In directly usable form?
If yes, then process it
If no, then invoke mediation
Discovery
Mediation
Process
Use
= Messaging

Intelligent Agents

- Software entities capable of independent (autonomous) action
  - Situation assessment
  - Problem solving
  - Inter-agent communication
  - Learning or adaptation

Types of User Assistants

- Information discovery
- Information dissemination
- Semantic mediation
- Matchmaker
- User interface assistance

Agent-to-Support Function Mapping

	Function Supported on Behalf of:	
Intelligent Agent Type	***User/Entity***	***NCIE Service***
Information Discovery	Find, access, retrieve information	
Information Dissemination		Discover and disseminate information
Semantic Mediation	Information translation and tagging	Information translation
User Interface:		
Basic User Interface	Tailor interface to user	
Personal Assistant	Enhance user interactions	
Matchmaker	Inter-agent negotiation	

Design and Development Challenges

- DoD enterprise “ontology”
- Agent reliability and “trust”
- Mobile code

Summary

- Although a “core enterprise service,” the vital role of the GIG user assistant has not been appreciated
- The user assistant must be “intelligent” and requires a DoD-wide “ontology”
- Agent technology introduces technical complexity and security concerns that are not being addressed